EBIS & LEBT Tests

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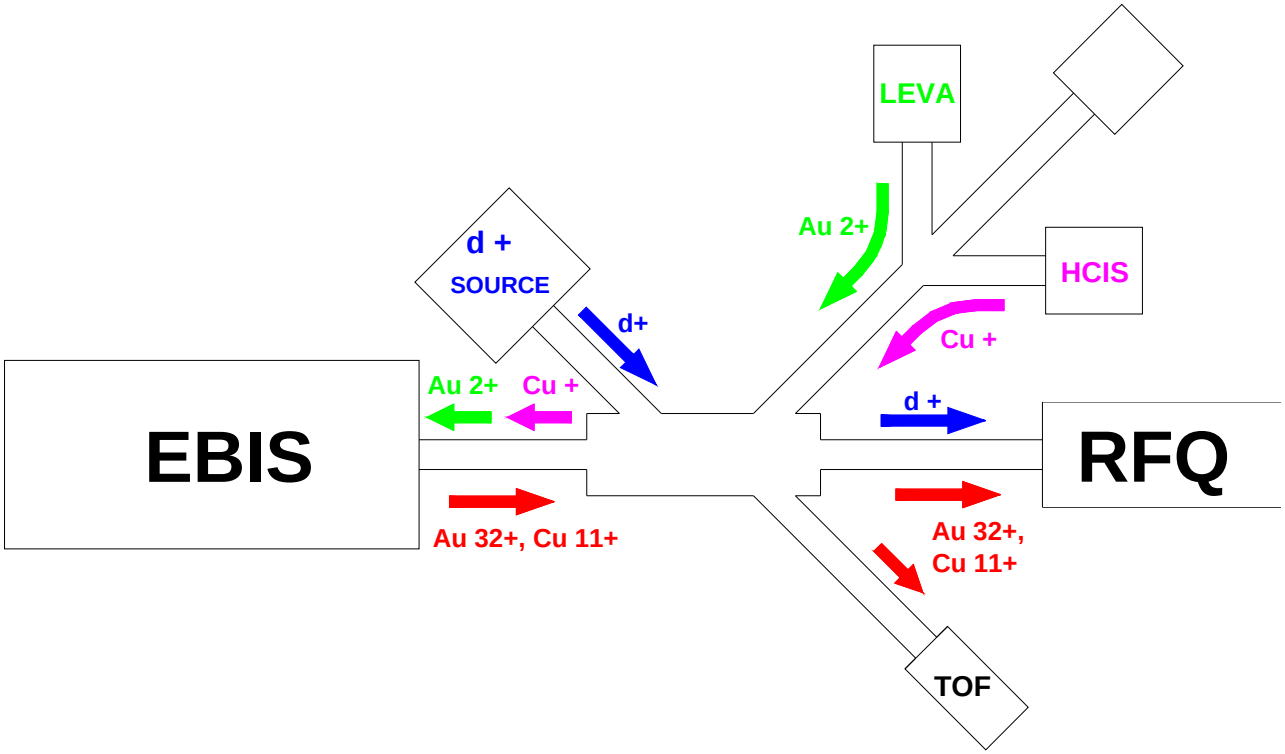
Introduction

Using the half-length, full instantaneous power prototype “Test EBIS” it was shown that sufficient ion intensities of various ion species could be obtained to meet the needs of RHIC and NSRL on a pulse to pulse basis.

The Test EBIS is now being used to demonstrate the appropriate HV acceleration and transport of the ion beams, to verify that the beams can be delivered with low loss through the LEBT and the RFQ.

To accomplish this, a fast switching HV platform and a high transmission LEBT switchyard have been developed.

Ion Injection and Extraction from the RHIC EBIS

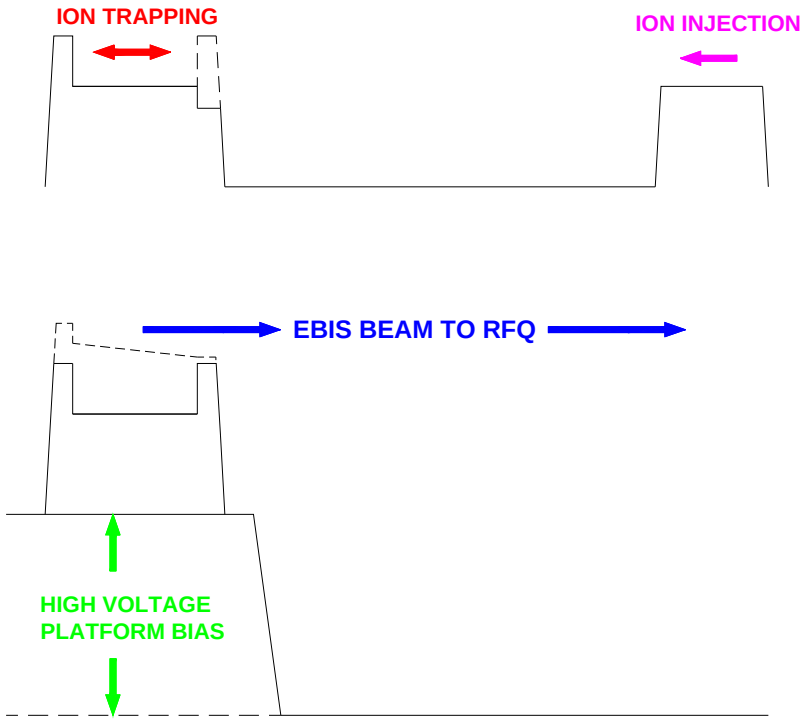


External ion injection provides the ion species; the EBIS acts purely as a charge breeder.

Advantages:

1. One can easily change species and charge state on a pulse to pulse basis
2. There is virtually no contamination or memory effect
3. Several relatively low cost external sources can be connected and maintained independently of the EBIS.

EBIS operation on a pulsed high voltage platform is necessary for injection into RFQ



During injection and confinement the RHIC EBIS operates at ground potential.

Just before ion extraction the EBIS platform voltage is applied such that the ions are extracted through a potential of up to 100kV.

In this way, the extracted EBIS ion beam attains the 17keV/amu needed for acceleration by the RFQ.

- **Benefits:**
  - –the high intensity EBIS ion beam is accelerated to full energy in a shorter distance than if the LEBT switchyard and ion sources resided on the HV platform
  - –ion sources can be accessed when the EBIS is operating on the HV platform

Goals for the Test EBIS

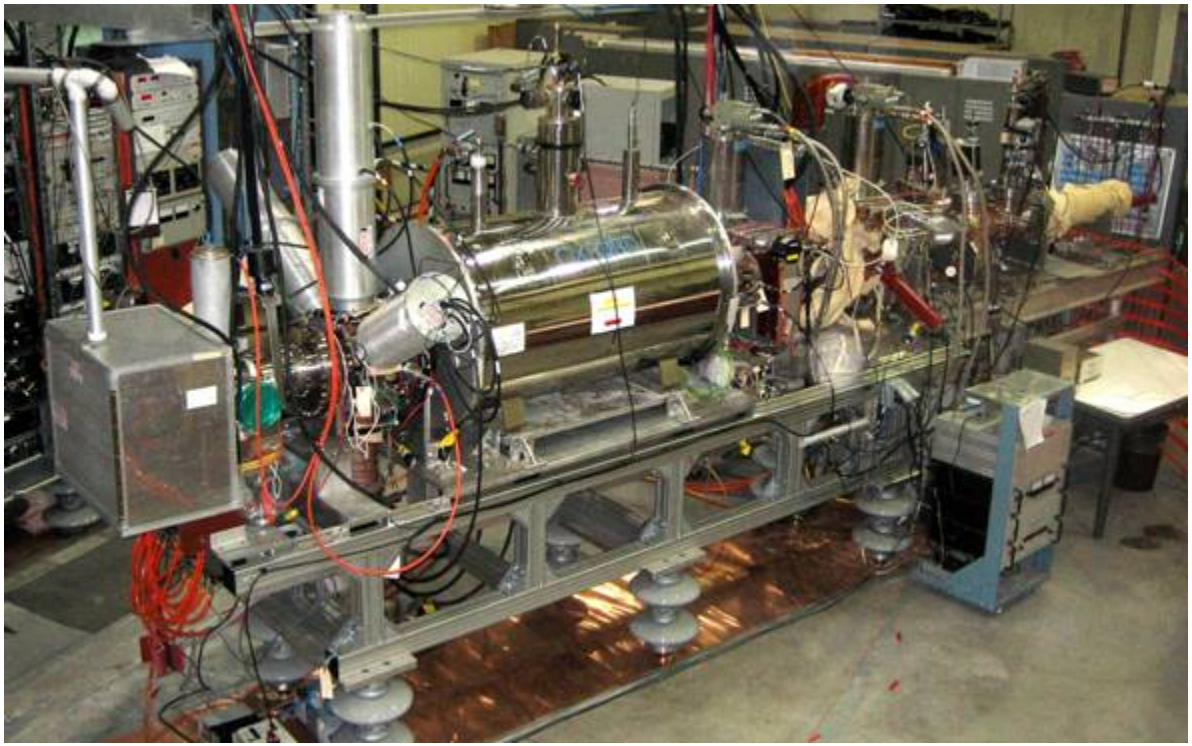
- **Develop hardware to operate on a 100 kV platform with the aim of transporting the extracted EBIS ion beam through the RFQ which will soon be commissioned in our laboratory.**
  - HV platform installation and pulsing (Done)
  - Build and test prototype LEBT Switchyard (Done)
  - Build and test New EBIS electron gun (installed, awaiting test)
  - Build and test New EBIS Collector & extraction optics (delayed, see Snydstrup)
    - New collector is a key item for achieving 5Hz pulse rate
    - New optics for low aberrations of extracted ion beams
  - Build and test LEBT Solenoid (tested, not installed – need pulsed PS)
  - Characterize EBIS emittance at final energy at RFQ location
  - Early test of RFQ at Test EBIS Location (Spring 2008)
- **By installing and testing prototype components at the Test EBIS as they become available, the transport of the high intensity Test EBIS beams approach the expected new EBIS performance.**

Test EBIS on HV Platform

- **During the installation of EBIS and power supply racks on the nominal 100 kV platform it was shown that the EBIS can be transported without a loss of critical alignment.**
  - The RHIC EBIS will be transported from assembly area to permanent location.

- **Hardware installed for testing includes:**
  - 100 kV, 200 kVA isolation transformer (prototype)
  - 100 kV Platform Pulser (<1ms rise time, prototype)
  - Capacitive Collector Supply (temporary for Test Facility use)
  - HV acceleration break
    - (temporary 8” diameter break installed in lieu of 12” on order)
  - Fiber optic control links
  - HV safety enclosure

Test EBIS on stand with high voltage isolation



Operation of the Test EBIS at over 80 kV extraction has been very successful.

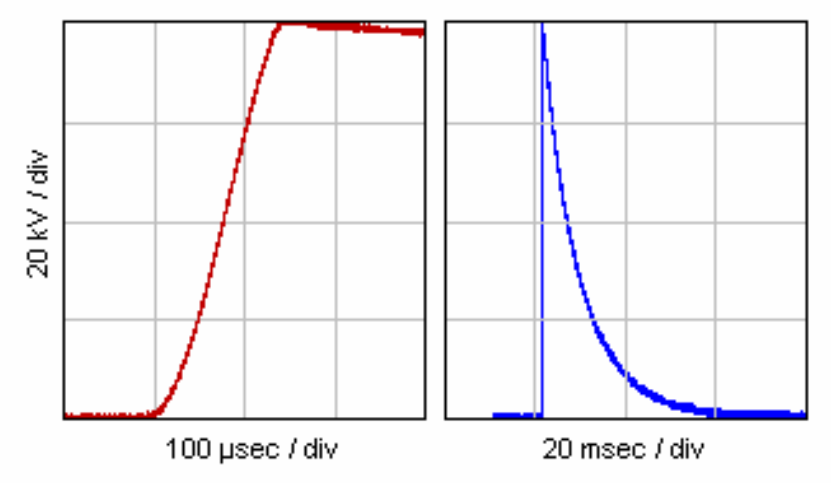
(an important test, validating HV isolation, HV iso transformer, HV pulser design)

No change in performance when platforms are pulsing

Emittance measurements are ongoing.

HV Platform Pulsing

Platform pulsing was tested to 100kV (only 80 kV needed for operation, since an additional ~20kV comes from ion trap potentials)



80kV pulsing of EBIS Platform:

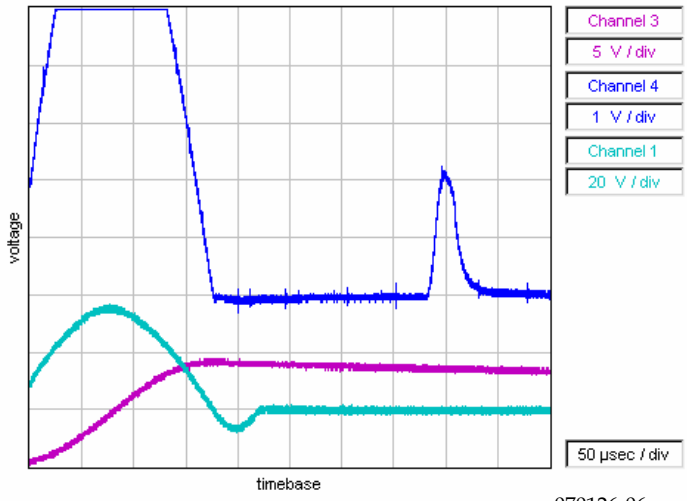
- 100µs/div shows rise time and Flat Top (Far Left)
- 20ms/div shows recovery to ground between EBIS cycles. (maximum EBIS Repetition frequency is 5Hz)

Ion extraction at 40kV + 17kV

Ch4: Toroid EBIS Ion current **(2mA, 25µs)**

Ch1: Primary current pulse (HV calibration)

Ch3: Internal Capacitive probe **(Rise time ~150µS)**



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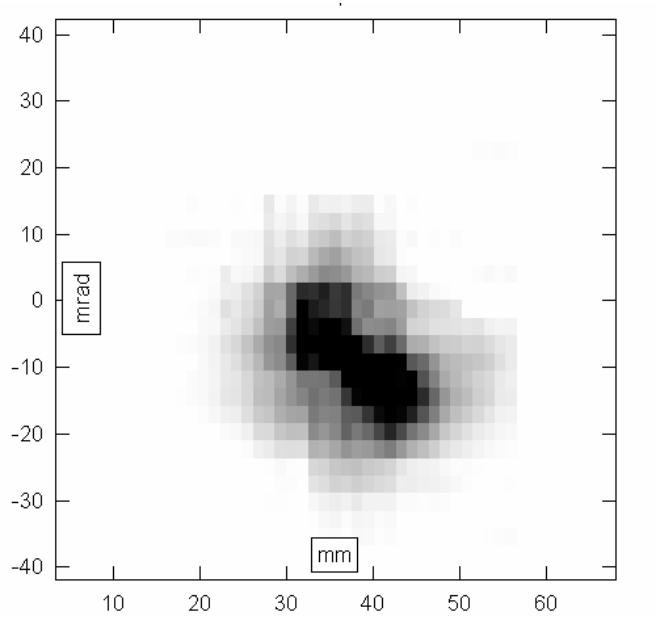
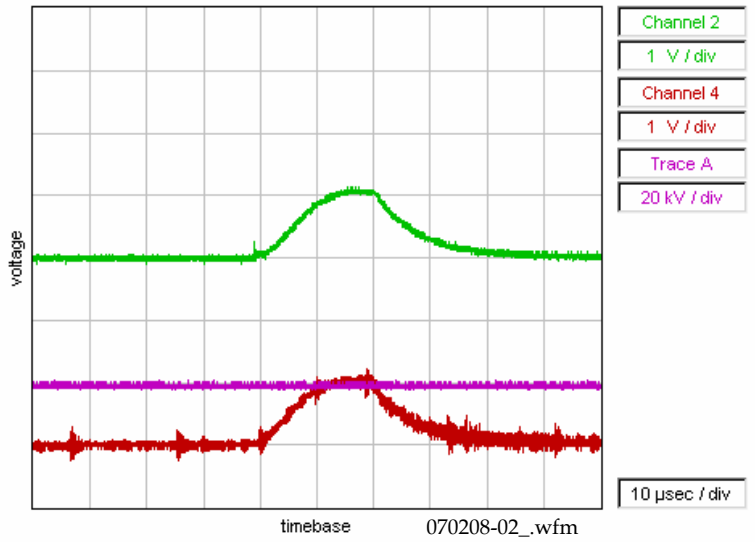
Slit-Foil Emittance Scan at 87*q kV





Ar ion spectra max at Ar^{4+}

70kV platform voltage
~17kV trap contribution

Emit (RMS norm)= 0.22 pi mm mr

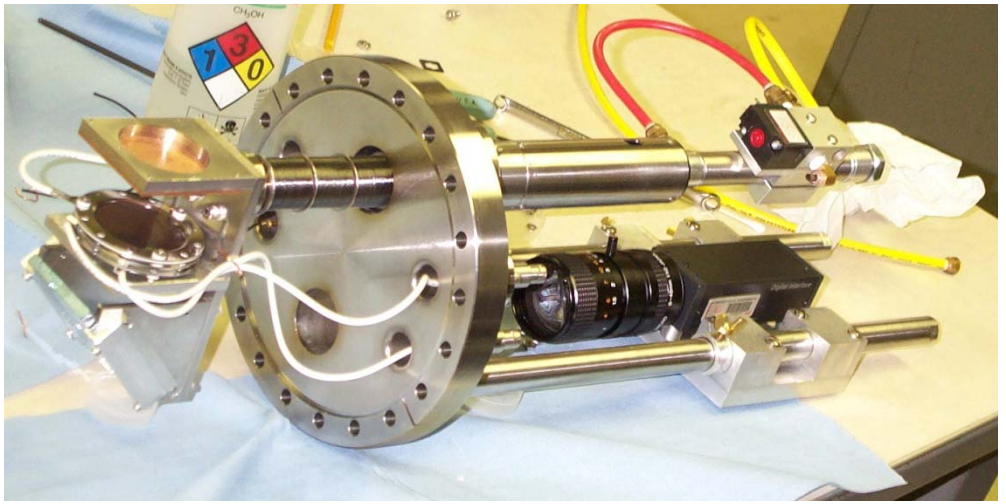
Ar ion current pulse (above)

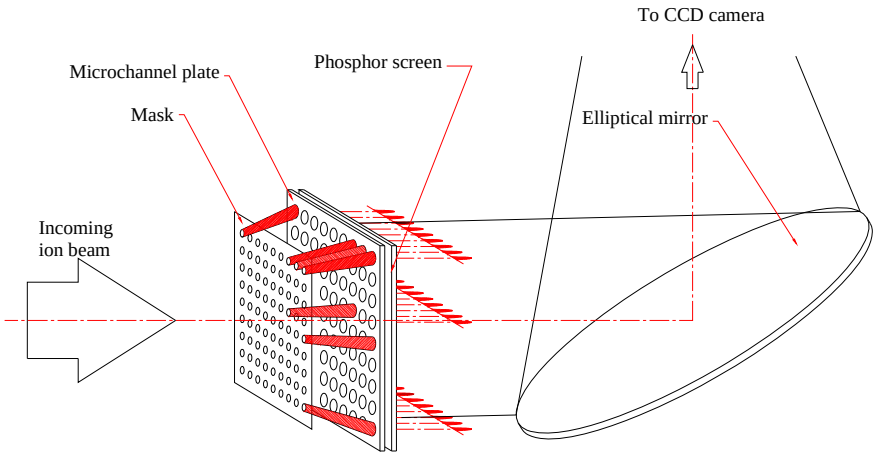
Ch2 (Green): ppot mask signal (1V=1mA)
Ch4 (Red): EBIS toroid (1V/mA)

1mA peak, ~20µS FWHM

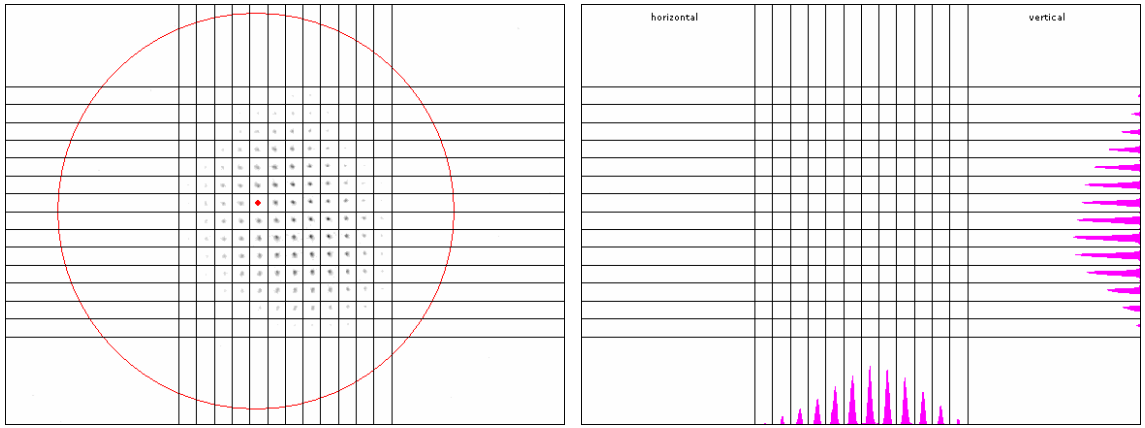
Pepperpot Emittance Head

- Acquires x and y emittance data in a single EBIS pulse
- Live beam profile image displayed provides immediate feedback to EBIS operator on beam focus
- Software provides pulse to pulse emittance calculation





Pepperpot Analysis of 87qkV Ar



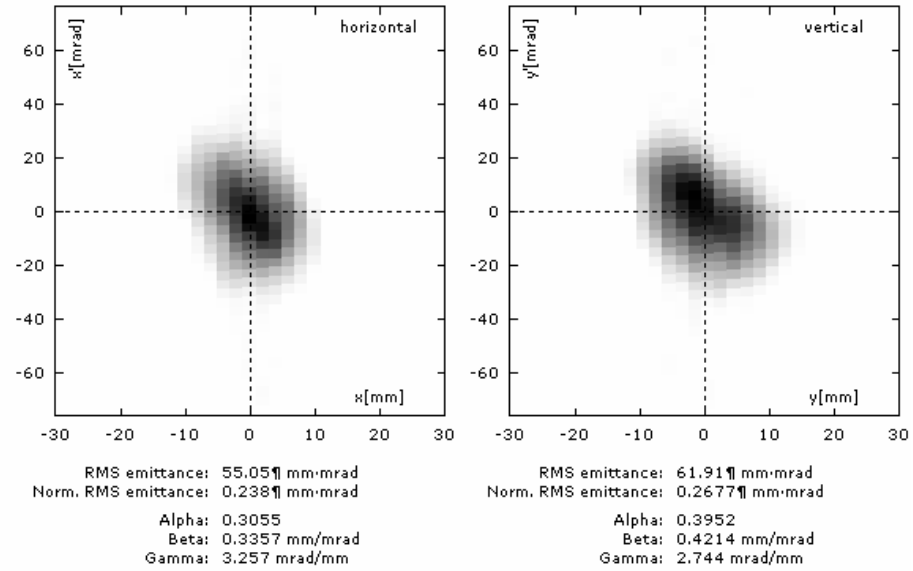
Shot to shot output:

Profiles (left)

Horizontal and Vertical emittances (below)

Ar spectra max at Ar^{4+}

70kV platform voltage
~17kV trap contribution



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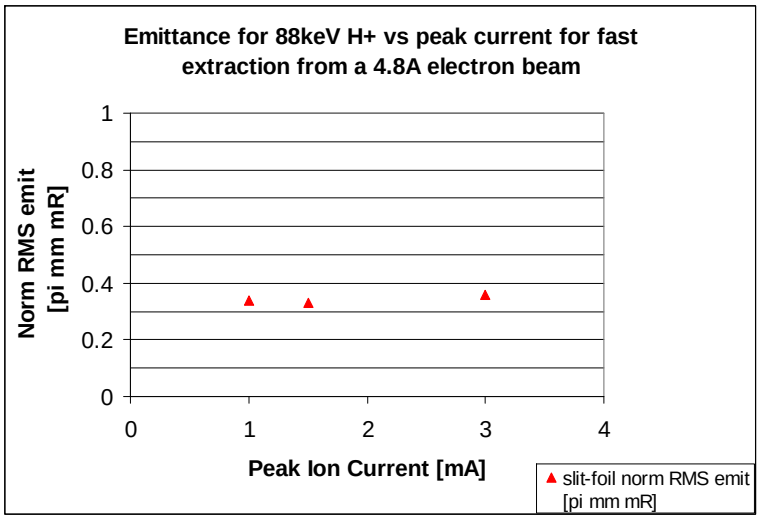
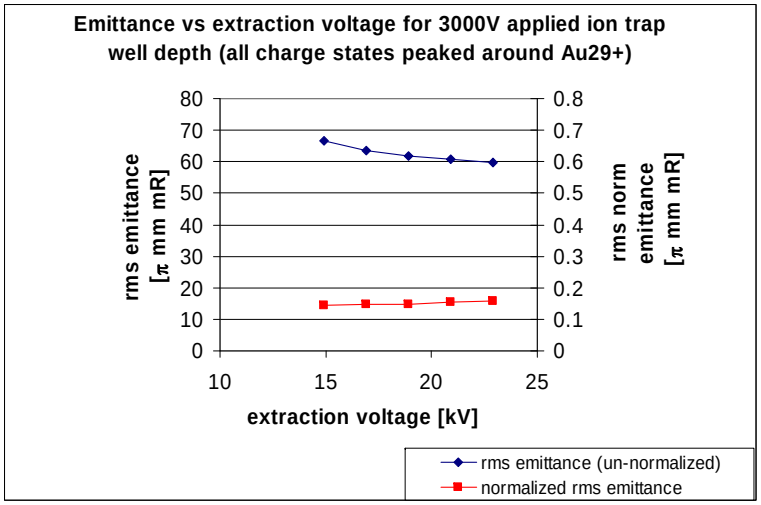
Slit-Foil Emittances of 88 keV H^+ and 15-25 qkeV Au^{29+}





Emittance of extracted EBIS 88 keV H+ ions using HV platform.

A single component H+ beam was used to avoid normalization uncertainty and to place an upper limit on the EBIS extracted ion beam emittance. (Ions were seeded by neutral gas injection).

Emittance of extracted EBIS 15-25 qkeV Au ions centered around Au^{29+}.

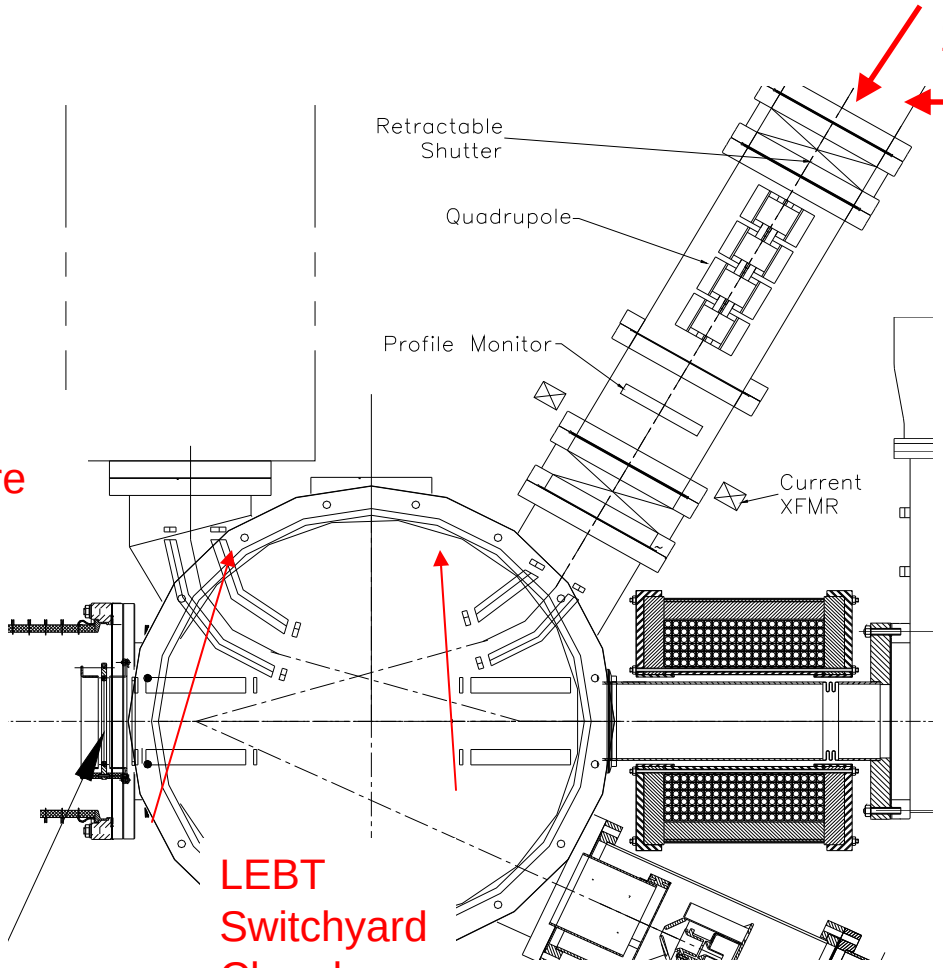
(Ions were seeded by ion injection before the HV platform was implemented).

LEBT Requirements

- Efficient matching between the EBIS and the RFQ
  - space charge of the 5-10 mA extracted heavy ion beam is a major consideration in the design
- Fast “switchyard”
  - singly charged ions from external sources are transported into the EBIS trap region
  - extracted, highly charged ions can be deflected to off-axis diagnostics (time-of-flight or emittance)
- Space for diagnostics for setup of ion injection and extraction

The line includes electrostatic lenses, spherical and parallel-plate deflectors, magnetic solenoid, and diagnostics for measuring current, charge state distributions, emittance, and profile.

Tests of Prototype LEBT



Tests with Cu 1+ from HCIS:

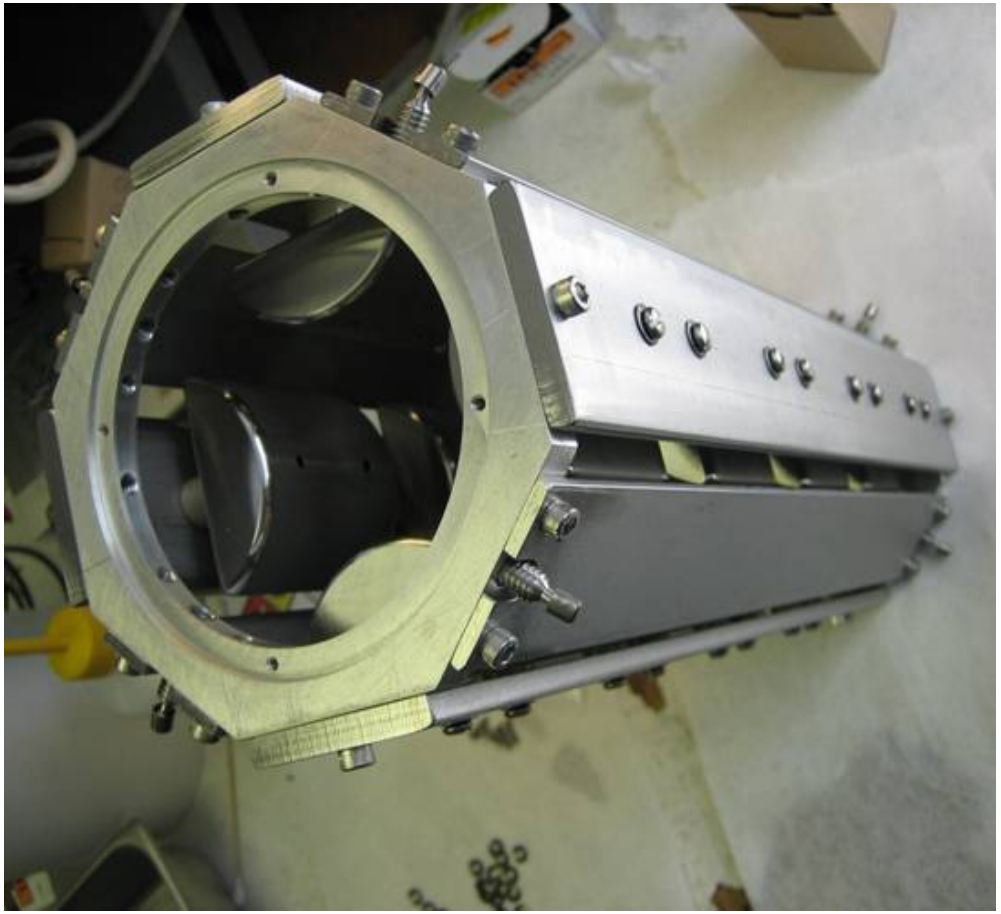
>90% transmission;

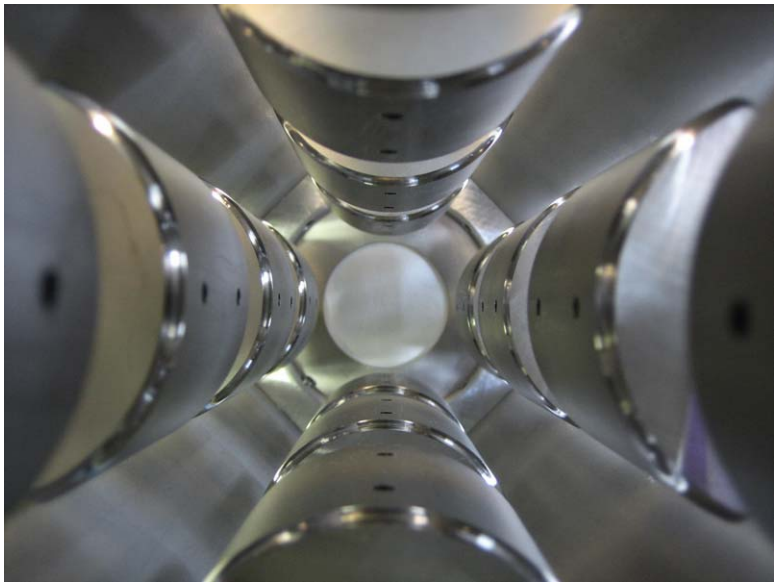
15 μA out, no collimation

100% transmission; collimated to 9 μA

This performance is more than adequate to obtain the required intensity of injected 1+ ions.

Electrostatic Quadrupole for transport of 1+ ions

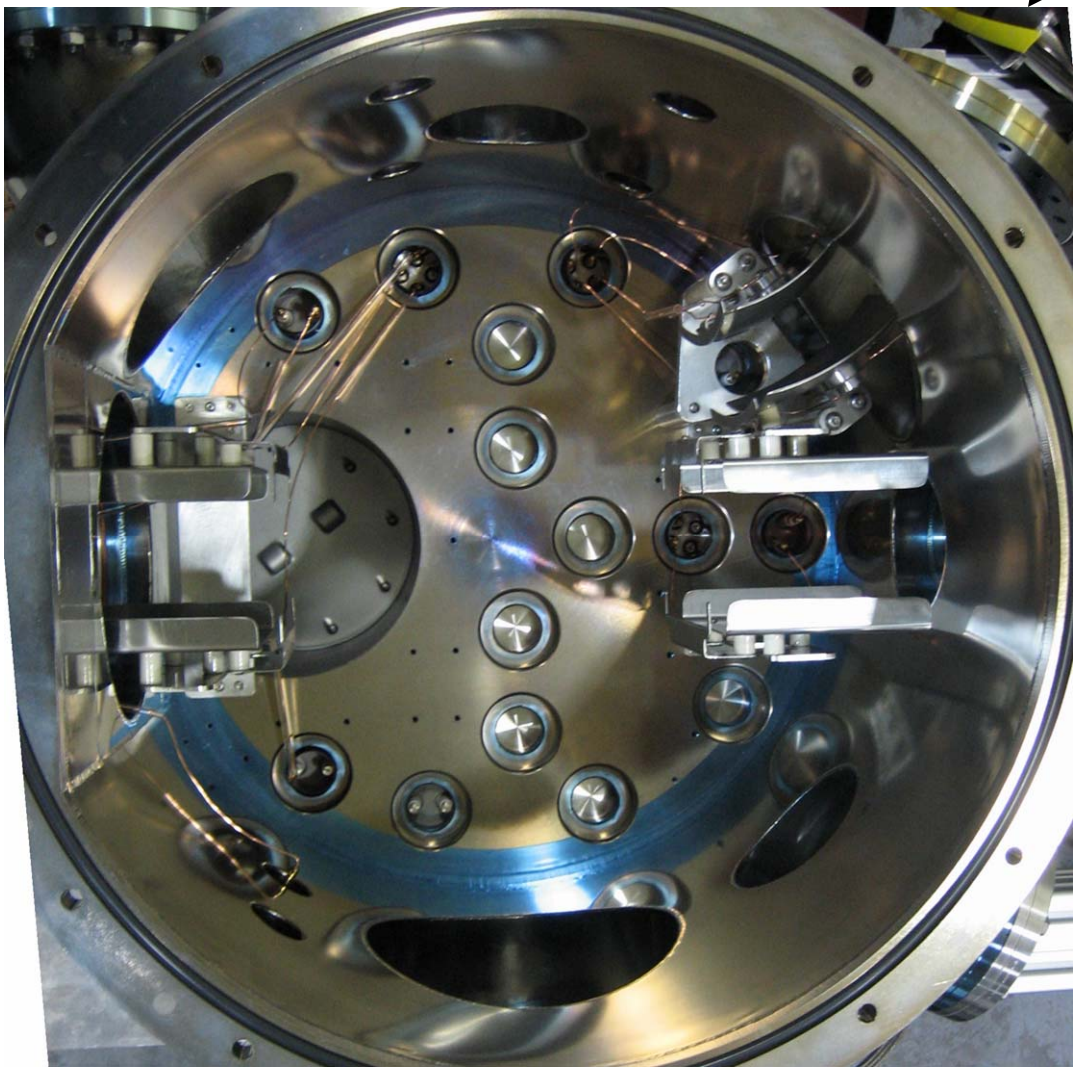




5 cm diameter aperture
5 cm long poles
2.5 cm between poles

LEBT Chamber

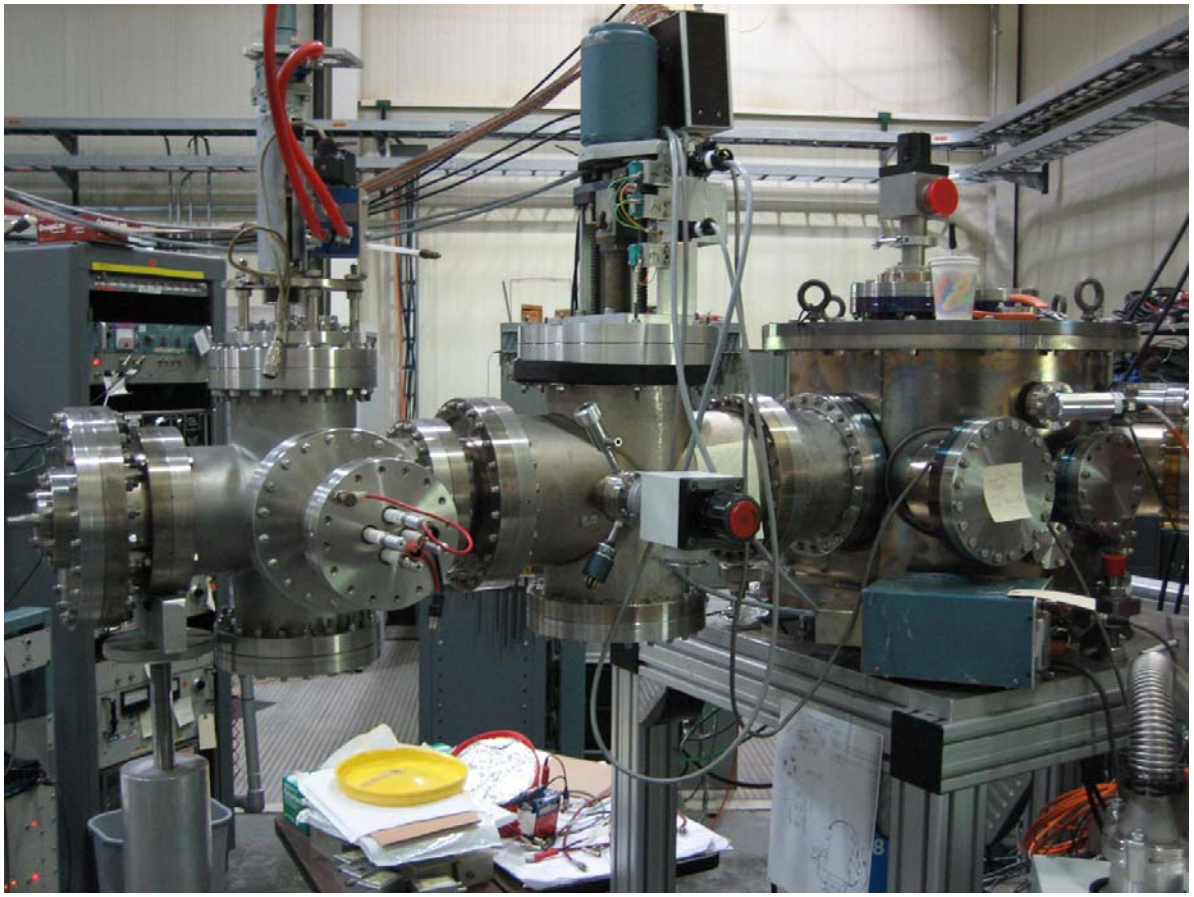
Beams from external 1+ sources



Beam from EBIS

Beam output to focussing solenoid and RFQ

Diagnostics at exit of LEBT chamber



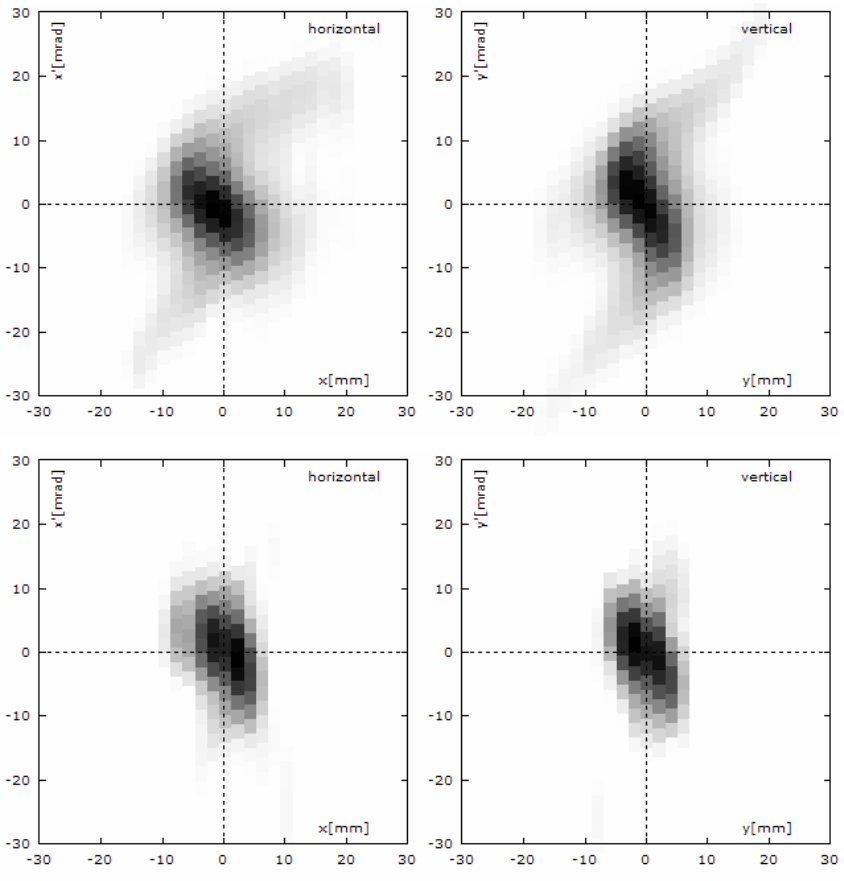
A: Pepperpot Emittance Head

B: Slit-Foil Emittance Head

C: LEBT Switchyard Chamber

(The slit-foil emittance head and four quadrupole lenses at the entrance of the LEBT Chamber are not shown in the picture).

Pepperpot emittance measurements of injected 1+ ions



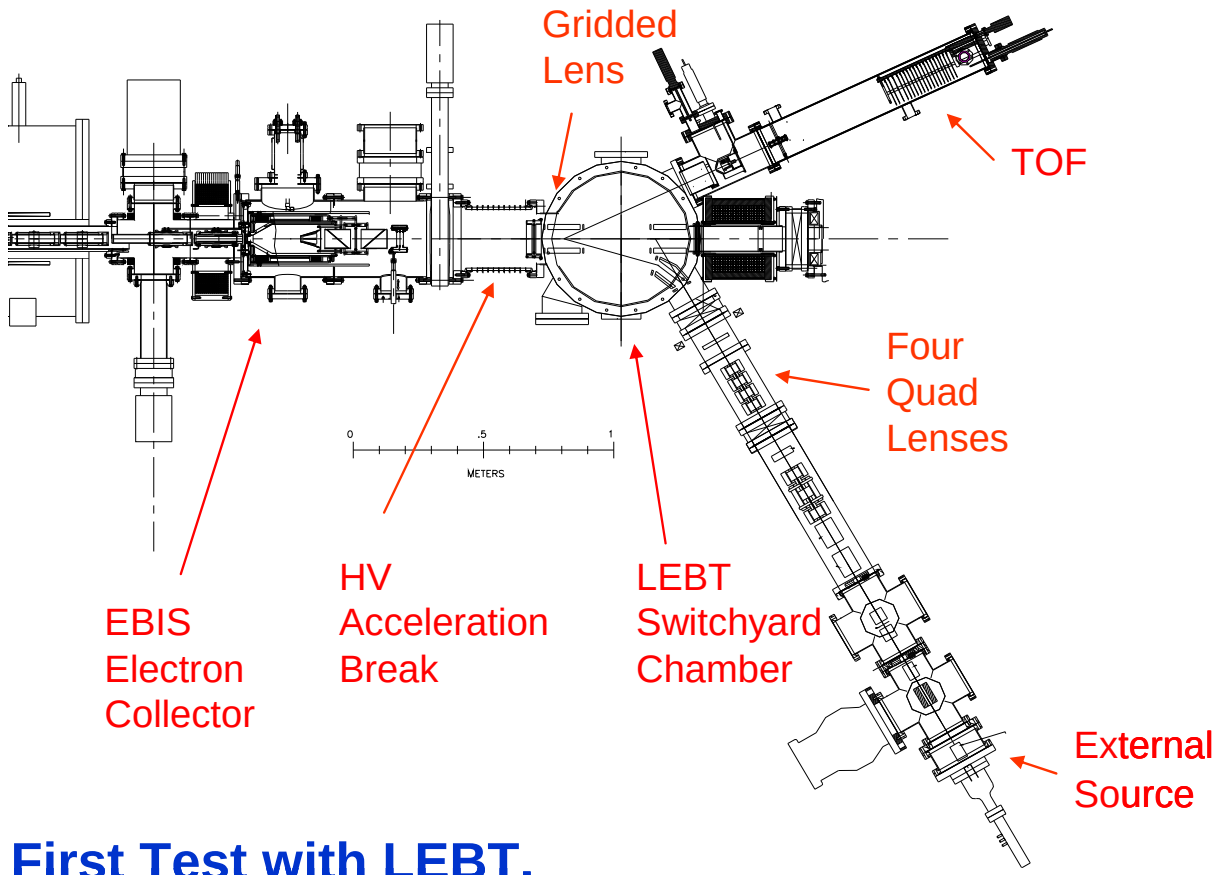
Emittance at the exit of the LEBT chamber, Cu^{1+}, 11 keV, 10 μA.

Aberrations are observed when the beam fills the quadrupole aperture.

Emittance at the exit of the LEBT chamber when the beam is collimated between the ion source and the first quadrupole.

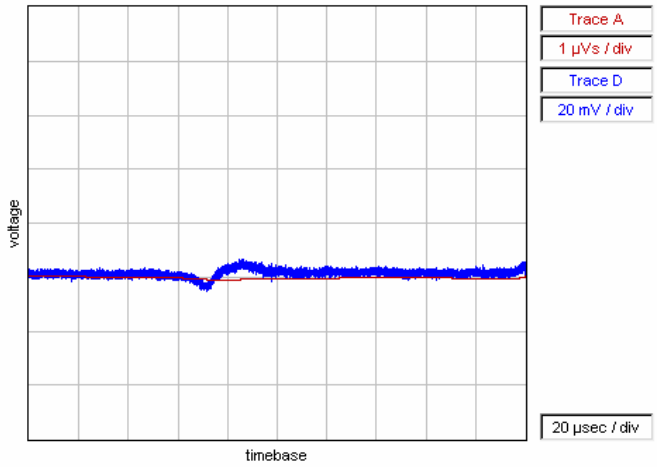
Pepperpot emittance measurements of injected Cu1+ ions. Output emittances with collimation are $\leq 0.02\ \pi$ mm mrad, norm., rms.

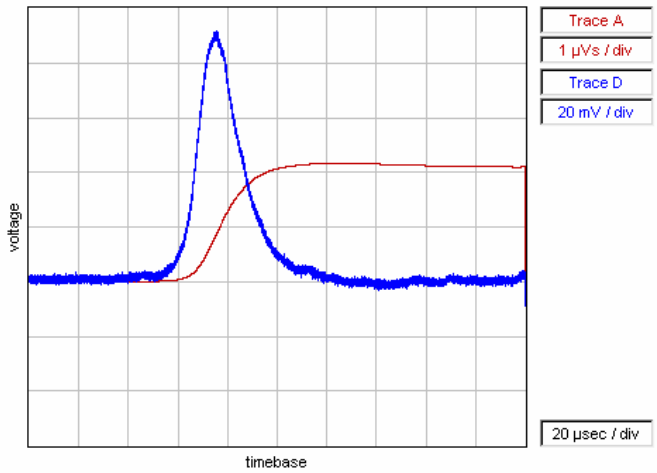
LEBT Switchyard on Test EBIS



First Test with LEBT,
ion injection and pulsed HV EBIS platform

First ion injection with New LEBT (Ne fast inj from HCIS)





Without Neon fast injection from HCIS and new LEBT

4.4A electron beam 4ms conf

HCIS beam stopped at FC1 before LEBT bend and Quads

With Neon fast injection from HCIS and new LEBT

Red: Net extracted Ion current

Blue: Integral of net extracted current

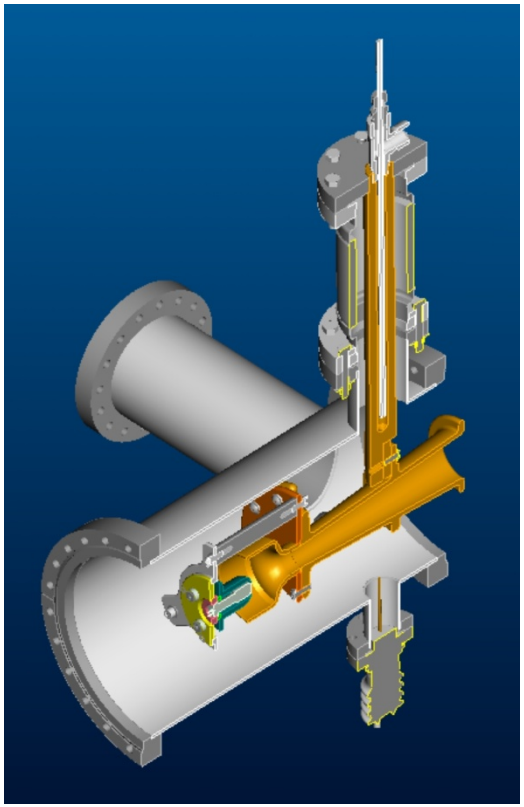
Next for the Test EBIS

- Test new electron gun already installed at Test EBIS
- Ion Injection Tests with new LEBT
- Ion Injection Tests with Slanted Mirror

- Install new collector and extraction optics
- Install new large aperture acceleration break

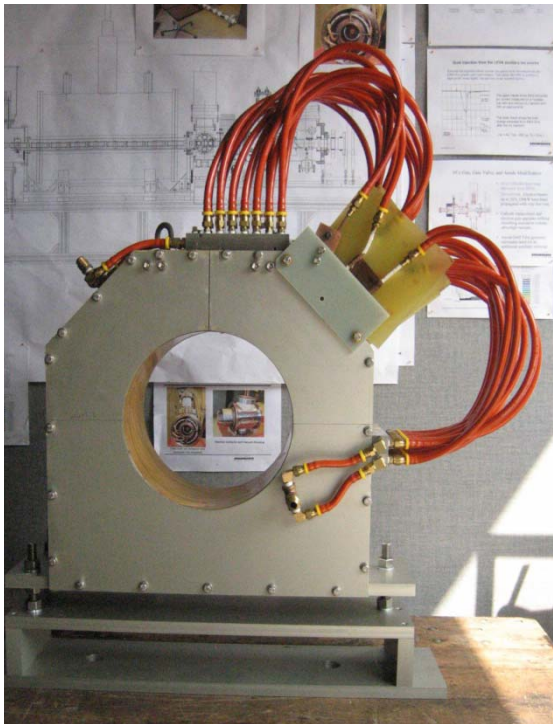
- Install LEBT Solenoid
  - Emittance tests with Ion Injection & High Energy Beam
- Tests with RFQ

Newly Constructed Electron Gun and Launch Solenoid

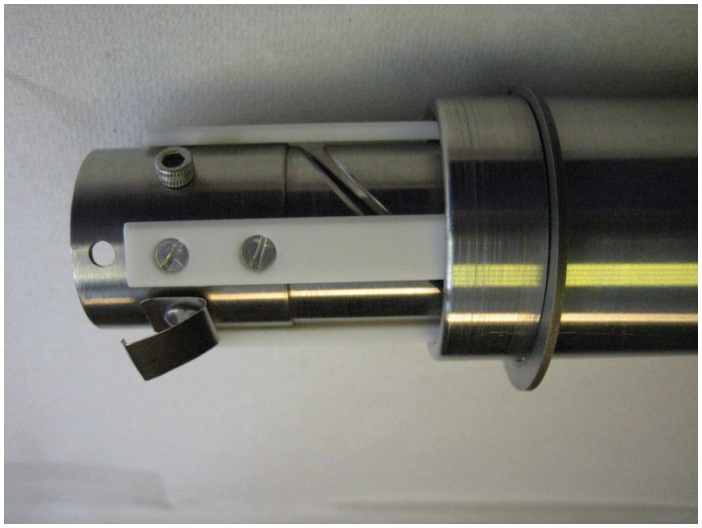


Electron gun schematic and physical assembly are shown above.

The electron beam launch solenoid is shown below.

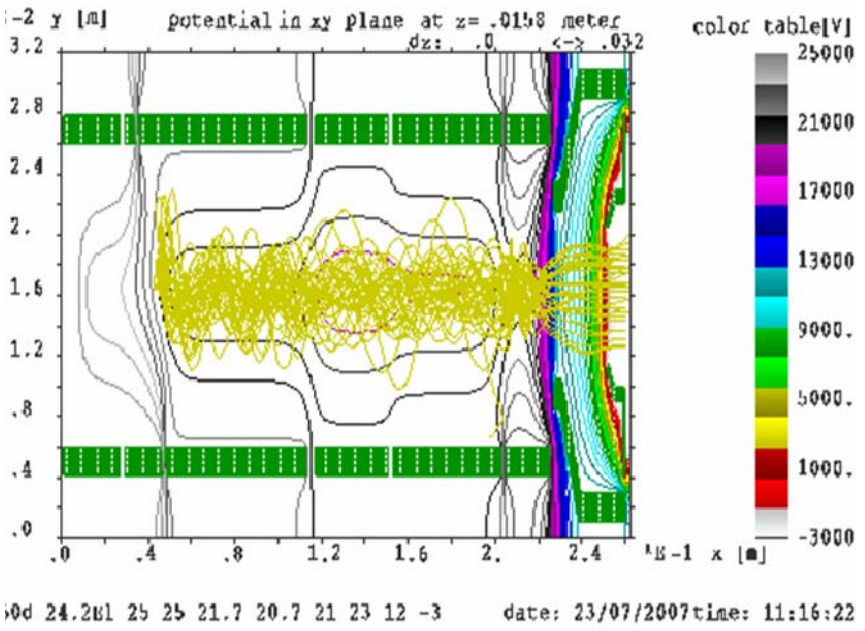


Slanted Mirror for ion injection studies



Installed at Test EBIS
inside Drift Tubes 2 & 3

Computer simulation showing improved ion accumulation in the EBIS trap after reflection from slanted mirror at left of schematic. (The electron beam trajectories are not shown).



SUMMARY

- **The Test EBIS has been operated on a pulsed HV platform with extracted ion energies up to 88 qkeV. Operation of the EBIS on the HV platform is very stable and reproducible.**
- **Tests with a capacitive collector supply verified that the RHIC EBIS collector supply can be unregulated.**
- **Emittance measuring capabilities using both pepperpot and slit-foil scanning devices have been developed. The emittance of light ions formed by gas injection appears to be about a two times larger than emittances of gold measured with ion injection. (0.2-0.4 pi mm mr vs 0.1-0.2 pi mm mr). This is consistent with expectations.**
- **A new LEBT switchyard has been built and ion beams from an external source have been transported through it with adequate intensities and beam properties. Injection tests into Test EBIS using the switchyard have begun.**
- **The first of the two new electron guns has been built and installed at Test EBIS for testing.**

Extra slides

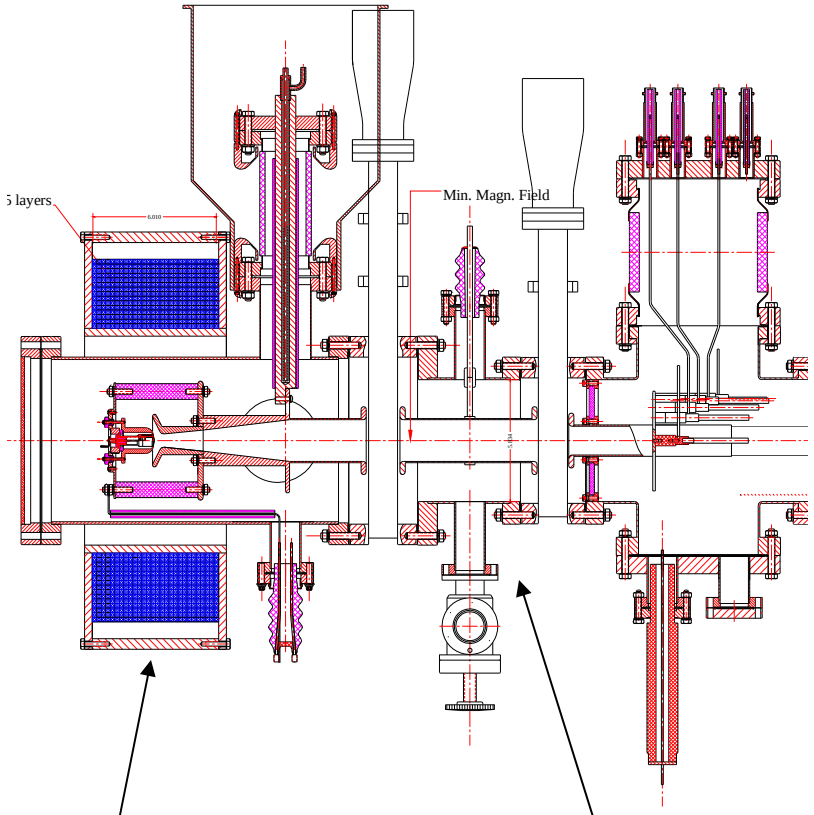
Performance Requirements of the RHIC Ion Source

Species	**He to U**
Output (single charge state)	**≥1.1 x 10^{11} charges / pulse**
Intensity (examples)	**3.4 x 10^{9} Au^{32+} / pulse (1.7 mA)** **5 x 10^{9} Fe^{20+} / pulse (1.6 mA)** **6.3 x 10^{10} He^{2+} / pulse (2.0 mA)**
Q/m	**≥ 0.16, depending on ion species**
Repetition rate	**5 Hz**
Pulse width	**10 - 40 μs**
Switching time between species	**1 second**
Output emittance (Au^{32+})	**< 0.18 π mm mrad,norm,rms**
Output energy	**17 keV/amu**

EBIS Results and RHIC Design Parameters

	Achieved	RHIC
Ion	Au^{32+}	Au^{32+}
I_e	**10 A**	10 A
J_e	575 A/cm^2	575 A/cm^2
$t_{confinement}$	35 ms	35 ms
L_{trap}	0.7 m ⟷	1.5 m
Capacity	5.1 x 10^{11}	11 x 10^{11}
% extracted ions	> 75%	50%
% in desired Q	20%	20%
Extracted charge	> 3.4 x 10^{11}	5.5 x 10^{11}
Ions/pulse	**> 1.5 10^9 (Au^{32+})**	3.3 x 10^9 (Au^{32+})
Pulse width	10-20 μs	10-40 μs
Rep. Rate	**0.5-2 Hz**	5 Hz

Gun and gun transition regions



- Replaceable electron gun chamber:
  - Minimized vacuum disturbance
  - Pre-conditioned electron gun
  - Fast turn around times
  - Increased EBIS reliability

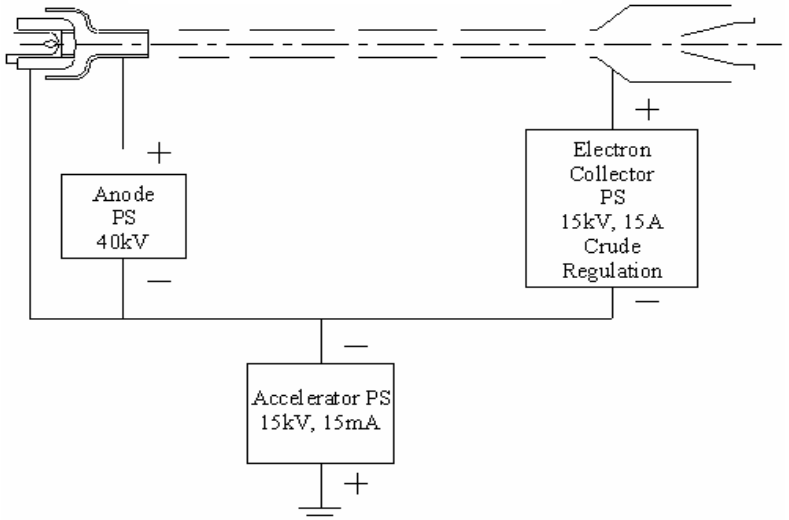
Electron Gun Chamber with Launching Solenoid

Buffer Chamber with Pump-out port (Not on Test EBIS)

Gun Transition Chamber

Capacitive Collector Supply on HV Platform

Test EBIS HV Platform &
RHIC EBIS Configuration

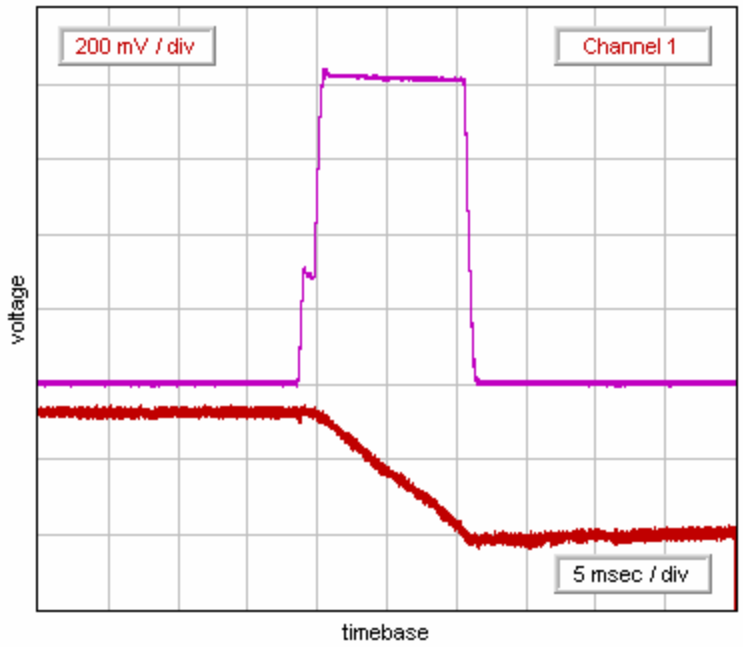


An unregulated, high current supply for electron beam collection

- A low current regulated supply to provide:
  1) stable e-beam launch
  2) Independent acceleration voltage
  3) Electron beam fault protection

A Collector Supply using a 125μF Capacitor and an 8kJ ALE charging supply has been built.

- 8A,10ms e-beam current pulse: (upper trace)
  V_sag: ~600V from nominal 10kV (lower trace)
  good e-beam propagation
- **Confirms that Unregulated Collector Supply can be used in RHIC EBIS**

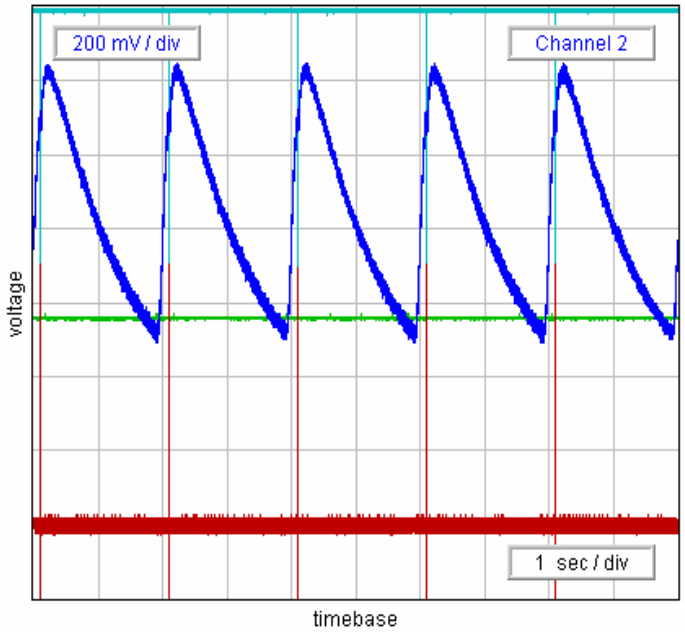


Controls

- Fiber optic links have been constructed and installed with our legacy EBIS voltage and timing control system to facilitate remote control of the elevated EBIS from the laboratory ground platform.

- Progress has been made in interfacing the EBIS voltage controller to two VME based PSI units operating with fast function generators provided by the controls group. The interface uses Fiber Optic Channels which provide Event Link connection to the EBIS system from the Linac Control room. The PSI units will be used to control the electron gun anode power supplies during the next quarter so that we can gain experience with the devices which will be at the new facility and also improve the integrity of the bipolar link.

He gas injection and TOF during periodic piezo-electric valve pulsing



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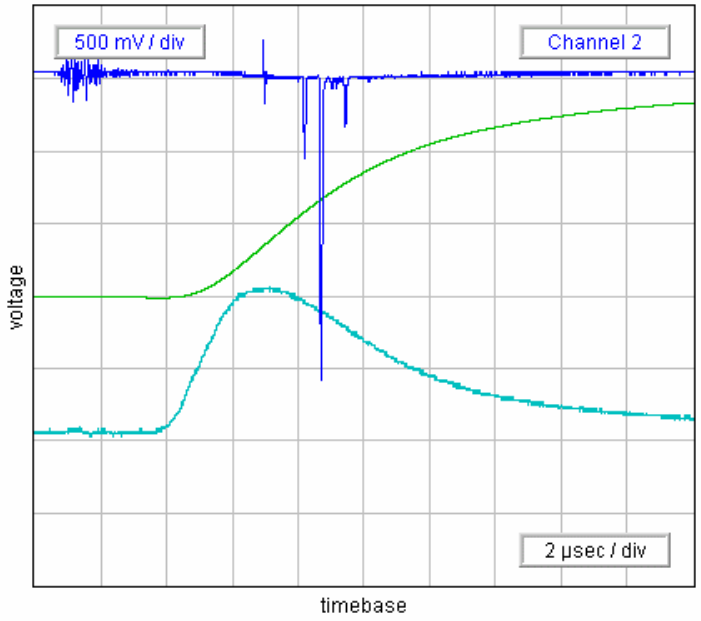
Valve: 340mT backing pressure
10ms injection time
0.5 Hz

Pressure variations on ionization region pressure gauge can be as large as a factor of 10 with present source conditions



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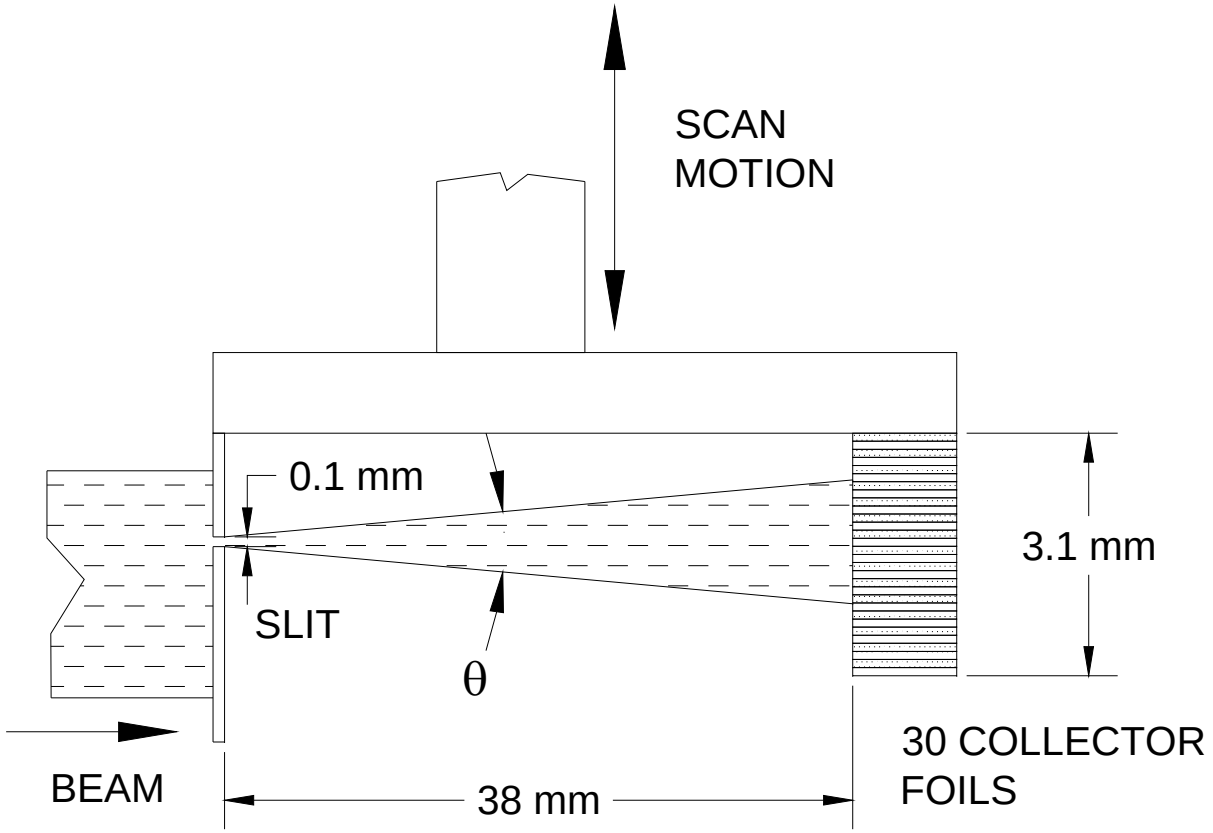
20.4nC Total charge after 3.6ms conf

Valve: 310mT backing pressure
1ms injection time
0.5 Hz

Slit-Foil Stack Scanning Emittance Head



Schematic of the emittance head. The head takes several minutes to scan through the EBIS pulsed Ion beam.